Lasers with Thin Strained InAs Layers in GaAs Electro−optical Characterization and Operation at Elevated Temperatures

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Experimental investigation on semiconductor lasers with thin strained InAs layers embedded in GaAs matrix are presented. The lasers exhibit high optical recombination efficiency (up to 35%), low threshold current density (0.12 kA/cm²) and wide temperature operation range (up to 100 °C). The emission energy of these laser structures can be varied by the configuration of the active region.

Introduction

Nowadays, InP based lasers are used for the emission wavelength 1.3 µm, although they have poor temperature properties due to shallow electron potential well. Quantum-size active structures and passive elements of lasers prepared by technology based on InP substrate are relatively expensive in comparison with the well-established GaAs-based technology. This cheaper and more advanced technology can use thin strained InAs layers or InAs quantum dots (QDs) in the laser active region to extend the emission wavelength towards 1.3 µm. The application of thin strained InAs layers as an active region in GaAs/GaAlAs waveguide seems to be promising for preparation of highly efficient and reliable near infrared lasers [1, 2]. However, it needs an extension of the emission wavelength closer to the 1.3 µm.

Recently, we have shown that emission energy of the lasers with thin strained InAs layers can be varied by the configuration of the active region [3−5]. In this paper, we focus on lasers with active region designed as a series of seven identical 0.5 nm thick InAs layers, separated by very thin GaAs spacers. These laser structures exhibited the longest emission wavelength and the lowest threshold current density. Their electroluminescence (EL) and photoabsorption (PC) properties at elevated temperatures (above 25 °C) are presented and discussed.

Experimental

The laser active layer surrounded by GaAs/AlGaAs waveguide was prepared by Low Pressure Metal-Organic Vapour Phase Epitaxy. Growths were performed in AIXTRON 200 MOVPE machine in horizontal low pressure reactor using TMGa, TMAl, TMIn, AsH_3, DETe and CCl_4 precursors. The growth process was carried in Pd diffused hydrogen gas under the total reactor pressure of 7 kPa. Growth temperature of 650 °C was used for $Al_{0.3}Ga_{0.7}As$ emitters as well as GaAs buffer and contact layers. For the growth of thin InAs and GaAs layers and the adjacent GaAs waveguide the growth temperature was decreased to 500 °C. (100) GaAs 10^{18} cm^{-3} Te doped substrates were used, as well as standard wet chemical etching before growth. Ohmic Au/Ni/Ge and Cr/Au contacts were evaporated at 200 °C and alloyed at 490 °C on the N-type substrate and P-type capping layer, respectively. The presence of the QD structures was excluded by photoluminescence (PL) measurement.

Structural properties of the active layer were analyzed by scanning tunneling microscopy − STM and transmission electron microscopy − TEM (JEOL 1200EX). PC and EL spectra together with the Watt-Ampere (W-A) characteristics were measured in the temperature range from 25 °C to 105 °C.

The PC spectra were recorded with different polarisation of the incident light (TE, TM) propagating parallel to the laser structure. The light in the wavelength range from 1.05 eV to 1.65 eV was provided by a tungsten lamp, dispersed by a grating monochromator (Jobin Yvon HR 640) and focused on the laser mirror. The resulting PC spectra were detected using conventional lock-in technique corrected with respect to the system response. The EL signal in the range of energies from 1.05 eV to 1.25 eV was analyzed by a grating monochromator with resolution 0.2 nm and detected by InGaAs detector. W-A characteristics were measured in the current range up to 2.5 A. Radiation power emitted from the front mirror was measured by optical power meter (Anritsu ML910B) with Ge detector. EL and W-A characteristics were measured under the same pulsed current excitation conditions. The pulse width of the excitation current was set to 200 ns and the pulse repetition rate to 10 kHz.

Results and Discussion

The active layer was grown as the multiple InAs/GaAs structure with 0.5 nm thick InGaAs layers, separated by 1.1 nm thick GaAs spacers. The schematic view of a laser active structure is shown in Fig. 1a and compared with similar active region with spacer thickness 5.3 nm, Fig. 1b (TEM). Bright and dark stripes, which appear on the both photographs, are caused by strain between In containing layers and surrounding GaAs. For thick separation GaAs layers (Fig. 1b), the designed periodicity was achieved. The InAs layers shows a remarkable broadening which may be caused by In diffusion. For the case of very thin GaAs spacer the separation of InAs was not observed, probably due to the formation of In modulated InGaAs layer. This has to be confirmed by atomic resolution STM.

PC and EL spectra measured on the laser with the lowest threshold current density and highest optical power (design with seven 0.5 nm thick In As layers in GaAs with 1.1 nm spacer) at 25 °C and 95 °C are presented in Figs. 2a and 2b, respectively. PC spectra measured with TE and TM polarisation show two absorption edges, which correspond to two transitions. The absorption edge of 1.18 eV measured at room temperature dominates the TE absorption spectra and disappears in the TM polarisation absorption where only the edge at 1.27 eV remains. This is because that only the transition between the lowest electron and light hole (e_1-lh_1) states is allowed for TM polarisation in strained layer. Therefore the absorption edges 1.18 eV and 1.27 eV of the room temperature TE and TM polarized PC spectra correspond to the transitions between electron and heavy hole or light hole ground states. Electroluminescence spectra were measured under conditions leading to spontaneous and stimulated emission with excitation current 0.2 A and 2.5 A, respectively. The low-energy edge of the spontaneous EL spectra follows well that of the PC and the stimulated emission takes place when the top of the absorption edge is achieved.

Temperature variation of the dependence of laser optical power on excitation current density (W-A characteristics) is presented in Fig. 3. The temperature dependence of threshold current density (J_{th}) and differential quantum efficiency are shown in Fig. 4. Temperature dependence of J_{th} was approximated by exponential function. Figure shows that the laser exhibit high optical recombination efficiency (between 25% and 35%) in the temperature range from 25 °C to 105 °C, the lowest threshold current density of 0.12 kA/cm² at the room temperature. The characteristic temperature is T_0 = 46 K for this temperature region and significantly increases with decreasing temperature [4].

In most samples an additional EL maximum appears with increasing operation temperature and excitation current. This effect is not typical for all laser with 7 quantum wells (QWs), see Fig. 5. For these lasers the high energy peak was not observed. Temperature dependence of the TE polarized EL spectra for 7 QW laser designed with widen out GaAs spacer is shown in Fig. 6. According to W-A characteristics measured at 25 °C, the investigated InAs/GaAs lasers can be divided into two groups: group A (J_{th} > 0.5 kA/cm²) and B (J_{th} < 0.5 kA/cm²). Figs. 7a and 7b show typical TE polarized EL spectra measured on lasers from group A and group B, respectively.

The energy difference of emission maximum (40 meV, approximately) is less than the corresponding difference between e-hh and e-lh transitions (~80 meV) and the light emitted from the lasers exhibits only TE polarisation (e-hh transition). Due to this, switching between e-hh and e-lh transition cannot explain this measured phenomenon. The possible explanation is transition from the electron to the first heavy hole excited state.

Conventional InGaAs QW lasers with the same In concentration and well thickness were prepared to compare their properties. The wavelength emission was similar, but the laser properties were much worse.

Conclusions

Laser structures with high optical recombination efficiency (up to 35%), low threshold current density (0.12 kA/cm²) and wide temperature operation range (up to 100 °C) were prepared. The wavelength emission of these laser structures will be varied by the configuration of the active region with the aim to reach 1.3 µm emission. The study of the mechanism of formation In modulated InGaAs or ordinary InGaAs for very thin GaAs separation layer will be continue.

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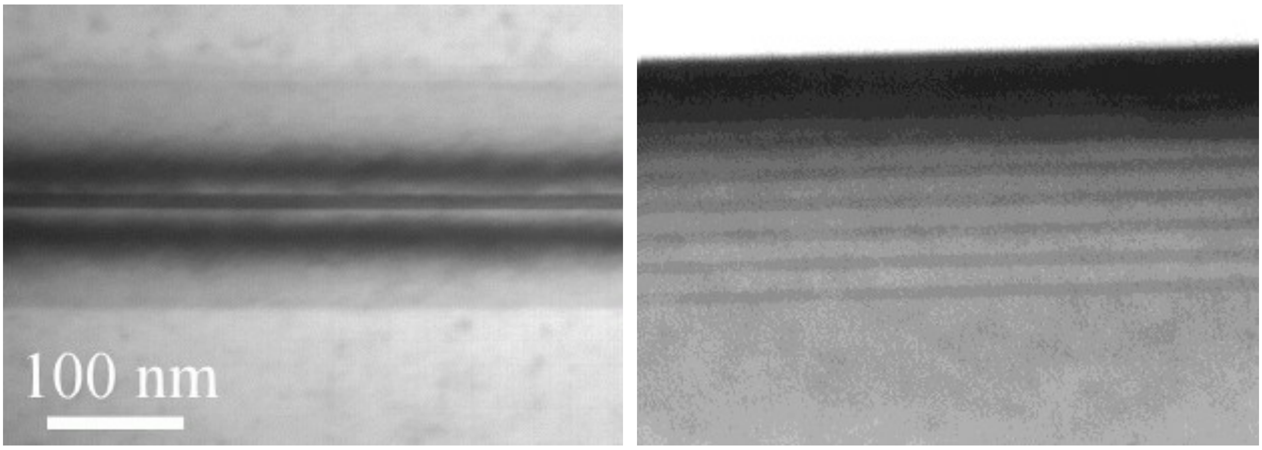
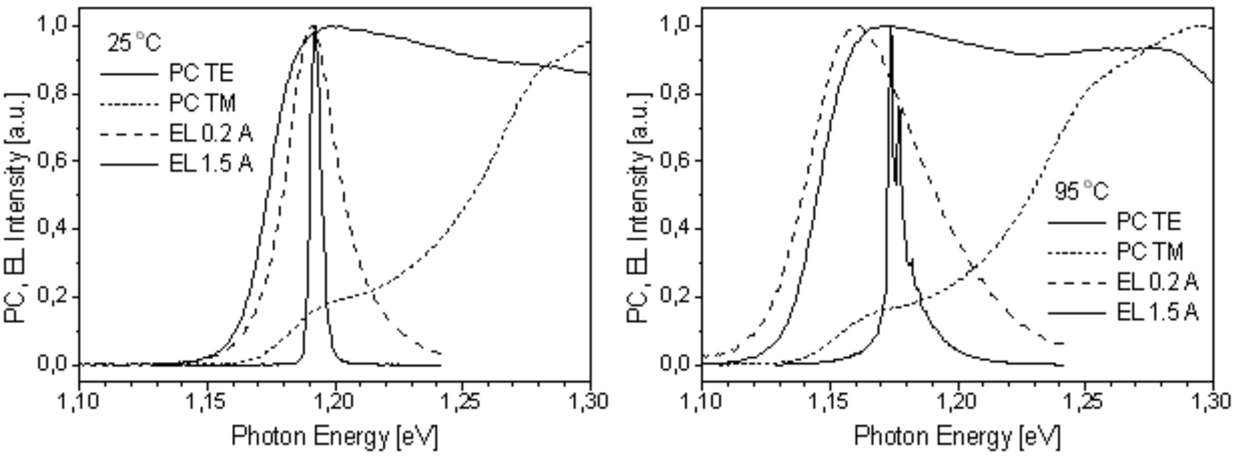


Figs. 1a, 1b − pictures of 7 QW laser structure TEM, a) 1.1 nm and b) 5.3 nm thick GaAs spacers (only part of the structure is visible).



Figs. 2a, 2b − photocurrent spectra measured with TE and TM polarisation and electroluminescence spectra measured under conditions leading to spontaneous and stimulated emission for temperature 25 °C and 95 °C, respectively.

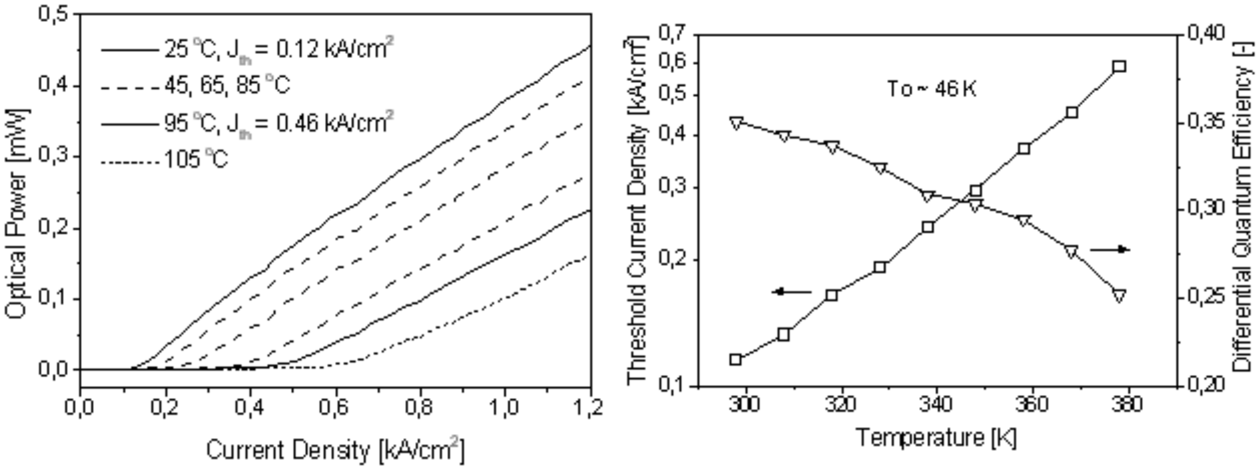
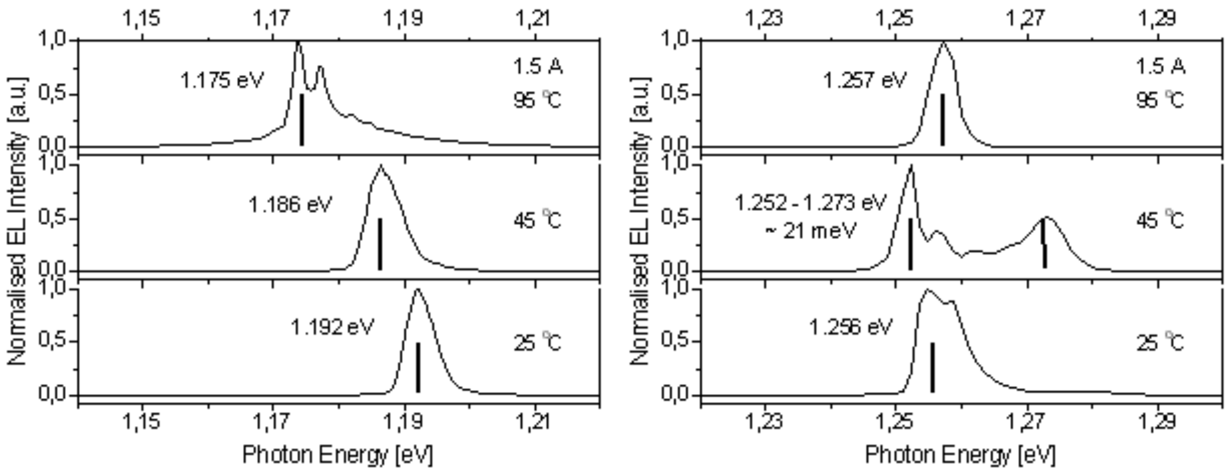
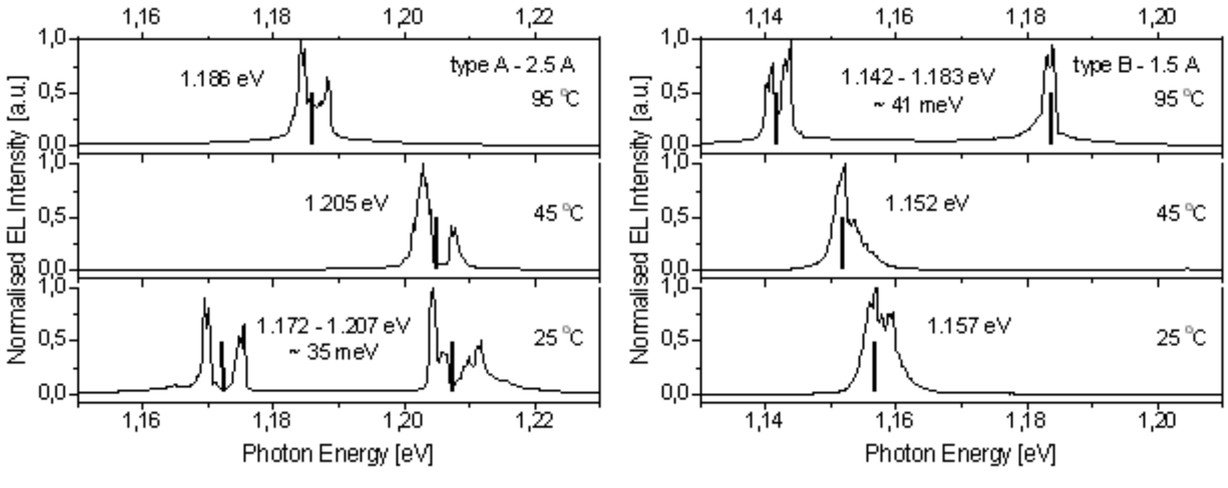


Fig. 3 − dependence of the laser optical output power on excitation current density for temperatures up to 105 °C (dotted line), with assignment of threshold current density for 25 °C and 95 °C (solid line). Fig. 4 − temperature dependence of threshold current density (squares) with characteristic temperature 46 K and differential quantum efficiency (triangles).



Figs. 5, 6 − temperature dependence of the TE polarized EL spectra for 7 QW lasers designed with different GaAs spacer thickness.



Figs. 7a, 7b − temperature dependence of the laser emission spectra with separated emission bands for type A and B lasers.